Nucleon Polarisabilities from Deuteron Compton Scattering, and Its Lessons for Chiral Power Counting

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Polarisabilities measure the global stiffness of the nucleon's constituents against displacement in an external electro-magnetic field. We examined them in elastic deuteron Compton scattering $\gamma d \rightarrow \gamma d$ for photon energies between zero and 130 MeV in Chiral Effective Field Theory χEFT with explicit $\Delta(1232)$ degrees of freedom, see Refs.[1,2] for details and better references. An excellent tool to identify the active low-energy degrees of freedom are the *dynamical polarisabilities*, defined by a multipole decomposition of the structure part of the Compton amplitude at fixed energy. Unique signals allow one to study the temporal response of each constituent.

For example, the strong, para-magnetic N-to-$\Delta(1232)$ transition induces a strong energy-dependence which is pivotal to resolve the "SAL-puzzle", see Fig. 1: While all previous analyses of the SAL-data at 95 MeV extracted vastly varying nucleon polarisabilities, χEFT with an explicit $\Delta(1232)$ captures correctly both normalisation and angular dependence of the data without altering the static (namely zero-energy) polarisabilities.

A consistent description must also give the correct Thomson limit, i.e. the exact low-energy theorem which is a consequence of gauge invariance. Its verification is straight-forward in the 1-nucleon sector, where the amplitude is perturbative. In contradistinction, all terms of the leading-order Lippmann-Schwinger equation of NN-scattering, including the potential (and hence one-pion exchange), must be of order Q^{-1} when all nucleons are close to their non-relativistic mass-shell, to accomodate the shallow bound-state.[3] In a consistent power-counting, all NN-rescattering pro-

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cesses between photon-absorption and emission must thus be included. Our Green's function approach embeds these diagrams to guarantee the Thomson limit, which is however statistically significant only below 70 MeV, see Fig. 1. Up to next-to-leading order, the only unknowns are contributions to the polarisabilities from short-distance Physics, leading to two energy-independent parameters. The iso-scalar Baldin sum rule is in excellent agreement with our 2-parameter fit, serving as input to model-independently determine the iso-scalar, spin-independent dipole polarisabilities of the nucleon at zero energy from all Compton data below 100 MeV:

$\alpha^s_{E1} = 11.3 \pm 0.7_{\mathrm{stat}} \pm 0.6_{\mathrm{Baldin}} \pm 1_{\mathrm{th}}$, $\beta^s_{M1} = 3.2 \mp 0.7_{\mathrm{stat}} \pm 0.6_{\mathrm{Baldin}} \pm 1_{\mathrm{th}}$

(in 10^{-4} fm^3). We estimate the theoretical uncertainty to be ± 1 from typical higher-order contributions in the 1- and 2-nucleon sector. Dependence on the NN-potential or deuteron wave-function used is virtually eliminated with the correct Thomson limit. Comparing this with our analysis of all proton Compton data below 170 MeV by the same method,

$\alpha^p_{E1} = 11.0 \pm 1.4_{\mathrm{stat}} \pm 0.4_{\mathrm{Baldin}} \pm 1_{\mathrm{th}}$, $\beta^p_{M1} = 2.8 \mp 1.4_{\mathrm{stat}} \pm 0.4_{\mathrm{Baldin}} \pm 1_{\mathrm{th}}$,

we conclude that the proton and neutron polarisabilities are to this leading order identical within (predominantly statistical) errors, as predicted by χEFT. More and better data from MAXlab (Lund) will lead to a more precise extraction, allowing one to zoom in on the proton-neutron differences.

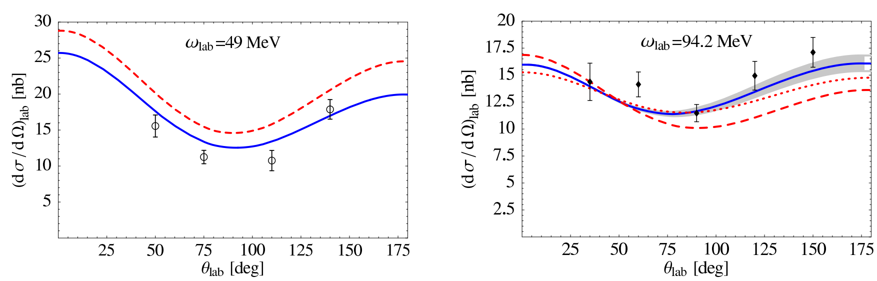

Figure 1. Left: Example of prediction using proton polarisabilities with (solid) and without (dashed) NN-rescattering in intermediate states. Right: Example of 1-parameter fit result using the Baldin sum rule for the deuteron (solid, with stat. uncertainty), compared to χEFT without explicit $\Delta(1232)$ ($\mathcal{O}(p^3)$, dashed) and to a fit[4] at $\mathcal{O}(p^4)$ ($\alpha^s_{E1} = 11.5$, $\beta^s_{M1} = 0.3$, dotted). From Ref.[1]

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